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High-productivity Operation of a Shaft-type Ferromanganese Smelting Furnace

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The ferromanganese smelting process at Mizushima Ferro Alloy Company Ltd was changed from electric-furnace operation to the use of a shaft type of smelting furnace (SF) in an attempt to reduce operating costs.

The SF began blow-in in June 1985, and has operated satisfactorily since then. Several operating technologies have been established, including a burden-distribution control method. The SF has an inside volume of 398 m^3, and a designed maximum productivity of 270 t/d of ferromanganese. The SF continued normal operation (less than the design maximum productivity) from 1985. From 1988, owing to the increasing demand for ferromanganese, the productivity of the SF was increased through several improvements to the operation. In August 1988 production reached 287 t/d. Oil injection was started in June 1989, with the aim of increasing the production still further by means of oxygen enrichment of the blast air, compensating for the theoretical flame temperature in front of the tuyères. The oil-injection rate is 53 kg/t, and the oxygen enrichment is 10,9 per cent. The replacement ratio of oil with coke is about 1,0.

By oil-injection and high oxygen enrichment, the productivity of the SF has been increased by 25 t/d over the productivity before the adoption of oil injection.

Introduction

At Mizushima Ferro Alloy Company Ltd, the electric-furnace method for the production of ferromanganese was replaced by a method using a shaft type of smelting furnace (SF) in 1985. The SF has generally functioned smoothly since its introduction. Since 1987, the company has also established several new operational techniques, the most important of which is control of the burden distribution by use of a one-hopper type of new bell-less top, called the Cardin type [1]. Until 1987, the output of high-carbon ferromanganese (HC FeMn) with the SF was less than 270 t/d (the design specification). With an increased market demand for HC FeMn and the introduction of a decarburization process for medium-carbon (MC) FeMn, efforts were made to increase production to more than 270 t/d. This paper describes the high-productivity operating techniques established as a result of this effort.

TABLE I
DESIGNED OPERATING PARAMETERS OF THE SF

Item	Specification (nominal)	Specification (maximum)
Inner volume, m^3	398	398
Production, t/d	230	270
Blast volume, Nm^3/min	500	570
Oxygen enrichment, %	7	10
Blast temperature, °C	860	860

Transition from Low-productivity to High-productivity SF Operation

The designed operating conditions of the SF are shown in Table I. From blow-in in 1985 to 1987, the SF was operated below its designed level of productivity because of depressed economic conditions following the appreciation of the yen in 1985.

Transition towards High-productivity Operation (October 1987 to November 1987)

After October 1987, the production of HC FeMn was increased to meet the higher demand following the start of MC FeMn production and a stronger demand from steelmakers. However, the uprating was not entirely smooth owing to the buildup of a 1 m thick crust (Ansatz) in the furnace throat. The crust buildup reduced the throat area, and resulted in a higher pressure drop of the blast in the shaft when the blast volume was increased. This meant that the operators were sometimes forced to decrease the blast volume.

The crust was removed with dynamite during a scheduled shutdown in November 1987. The improved furnace profile after the crust had been removed made it possible to increase production to 265 t/d. Operating conditions during the transition to higher production are shown in Table II.

High-productivity Operation using High Oxygen Enrichment and High TFT (December 1987 to January 1988)

The goal of the originally planned production increase was

TABLE II
OPERATING CONDITIONS DURING THE TRANSITION TO HIGHER PRODUCTION

Item	Sep. 1987	Nov. 1987	Jun. 1987
Production, t/d	194	265	262
Blast volume, Nm^3/min	520	570	580
Blast temperature, °C	830	800	810
Oxygen enrichment, %	5,4	7,4	9,0
Blast moisture, g/Nm^3	21	22	24
Theoretical flame temp, °C	2 433	2 518	2 610
Permeability, $g/cm^2/Nm^3/min$	1,545	1,492	1,511
Coke rate, kg/t	1 650	1 520	1 530
Dust generation, kg/t	200	191	235
Mn yield, %	91,7	93,1	90,3

achieved when production was raised to 265 t/d in November 1987. However, in order to realize a further increase in production, the oxygen-enrichment ratio was increased to 9 per cent. This resulted in a higher theoretical flame temperature (TFT) of 2610 °C, and in increases in both the amount of wet dust (sludge) generated and the Mn content of the sludge, which rose from 17 to 20 per cent. The blast volume was raised from 570 to 590 Nm^3/min, which caused a sharp increase in the dry dust collected at the dust catcher (DC dust). The attempt to increase production by raising the blast and oxygen-enrichment levels thus ended in failure, since these practices resulted in an unacceptable increase in the loss of Mn to dust.

The relationship between the TFT and the Mn content of the sludge is shown in Figure 1, and that between the TFT and the rate of sludge generation in Figure 2. From these diagrams it can be seen that the TFT is correlated positively both with an increased Mn content in the sludge and with the rate of sludge generation. The cause of these phenomena is presumed to be an acceleration in the rate of Mn evaporation in the raceway in front of the tuyère as the TFT increases.

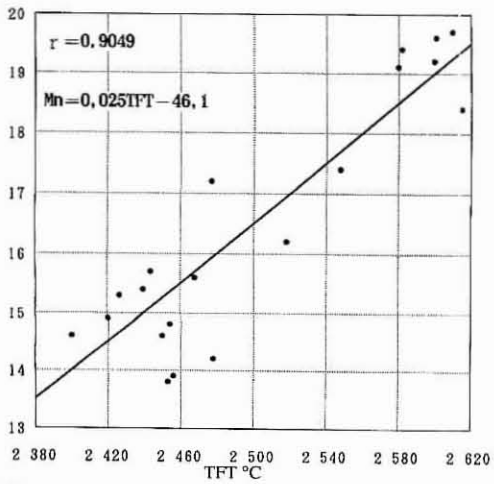

FIGURE 1. Relationship between TFT and Mn in sludge

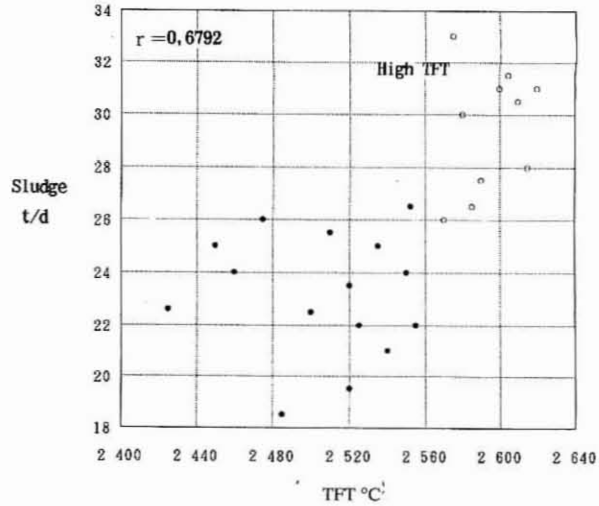

FIGURE 2. Relationship between TFT and sludge generation (o: High TFT operation)

The trends in the temperature of the hot metal and the Mn content of the slag during the period of transition are shown in Figure 3, which indicates that the Mn content of the slag increased with increased output in the period from September 1987 to January 1988. In addition to the Mn lost to the sludge, the Mn lost to the slag resulted in a lower Mn yield, particularly during January 1988. It was presumed that this was due to the rate of the reduction reaction, shown in equation [1], failing to keep pace with the speed at which the ore was melting and descending through the furnace at higher levels of production, resulting in a disequilibrium in the two processes:

$$MnO + C = Mn + CO. \qquad [1]$$

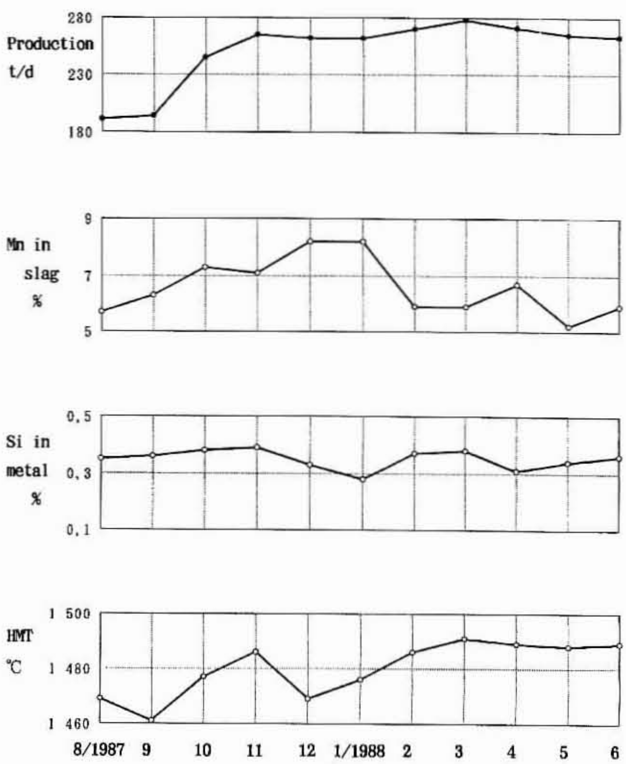

FIGURE 3. Trends in production

Stable Operating Techniques for High Productivity

As it was not possible to achieve increased production by the means described, operational improvements were adopted to limit the Mn loss, making it possible to establish new production records of 278 t/d in March 1988 and 287 t/d in August 1988, as shown in Figure 4. The techniques that led to the high smelting productivity are discussed below.

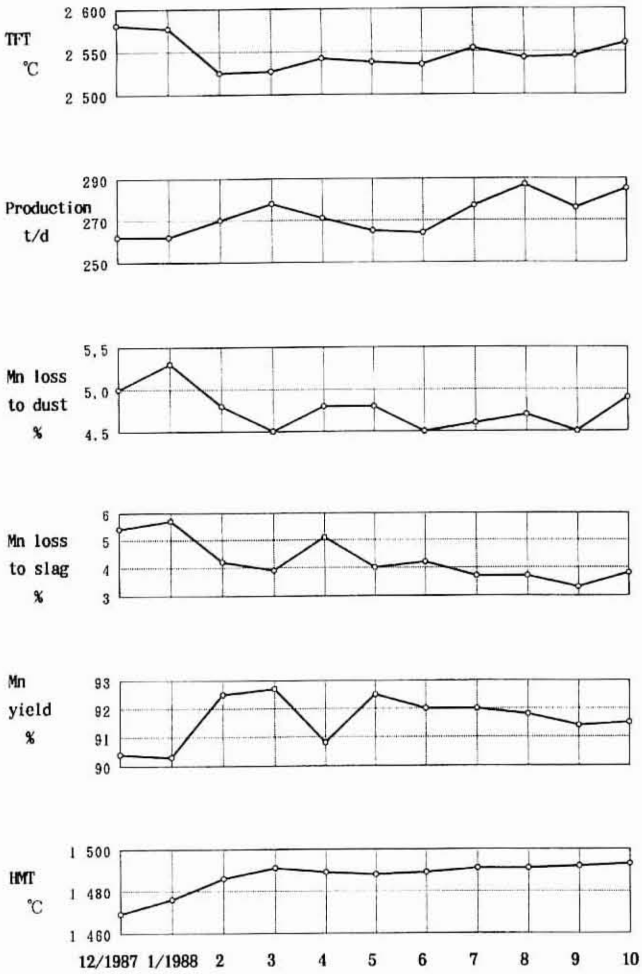

FIGURE 4. Trends in conditions for high-productivity operation

Decreased Dust Generation as a Result of TFT Control

As shown in Figure 2, sludge generation increases rapidly at TFTs above 2550 °C. The manganese content of the sludge also increases as the TFT rises. Operation was therefore conducted at a TFT control standard of under 2550 °C, beginning in February 1988. Figure 4 shows the trends of the important operational factors. The losses of Mn to dust decreased sharply by 0,8 per cent between January and March 1988, while the Mn content of the sludge was stabilized at the low level of 13 to 15 per cent after March 1988 (Figure 5). That value, however, was less than the targeted regression value, and it was assumed that the actual TFT during that period had fallen below the calculated TFT as a result of the increase in production. Consequently, the controlled TFT level was revised upwards to 2570 °C, which made it possible to increase the oxygen-enrichment ratio to 8,4 per cent and thereby achieve increased production.

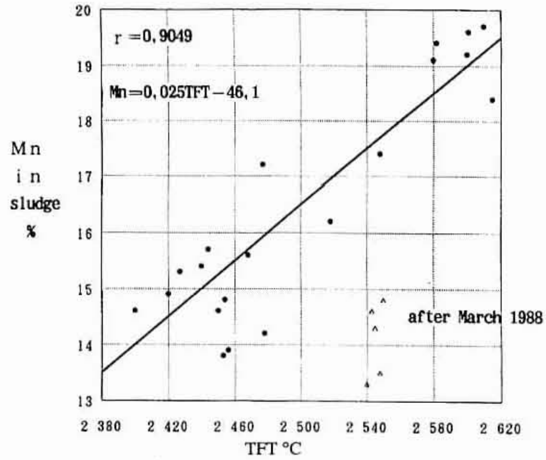

FIGURE 5. Relationship of TFT and Mn in sludge

Decreased Mn loss to Slag as a Result of Hot-metal Temperature Control

During the transition to high-productivity operation, the Mn yield decreased because of higher MnO contents in the slag. This, as mentioned above, was because the rate of the MnO reduction was slow relative to the melting of the semi-reduced ore at the hearth. To accelerate the MnO reduction reaction, it was necessary to increase the hot-metal temperature (HMT) and/or the activity of the MnO by increasing the basicity of the slag. The target minimum HMT was raised from 1460 to 1480 °C, and the basicity control was improved. As a result, the manganese content of the slag was reduced to less than 6 per cent, and the Mn loss to the slag was lowered by 1,5 per cent. Reductions in the Mn losses to dust and slag resulted in a 2,4 per cent improvement in the overall Mn yield between January and March 1988. During that period the silicon content of the metal was constant.

Burden-distribution Control in Period of High Productivity

Control of the gas-flow distribution is a very important factor in the operation of a shaft-type furnace. An excessive central gas flow raises the top-gas temperature, which increases the generation of dust, while excessive circumferential flow places a heavier thermal load on the furnace wall and may result in burden-descending problems such as slips and hangings. The Cardin type of bell-less top was therefore installed to control the gas-flow distribution.

Although coke and ore are generally charged into shaft furnaces in alternate layers, the Mizushima SF uses a mixed-charging method, in which a mixture of coke and ore is charged with the aim of improving the gas permeability and the reactivity of the coke and ore.

Burden-distribution control method for mixed charging

In the conventional burden-charging method, a gas path with good gas permeability is maintained by the coke layer, and the radial gas distribution is controlled by changing the radial distribution of the thickness of the ore layer. For example, the peripheral gas flow can be depressed by charging more ore near the furnace wall. On the other hand, in the mixed-charging method, the gas flow is controlled by charging different ratios of premixtures, using a different charging pattern for each premixture. The basic concept of gas-flow control used with the Mizushima SF is as follows:

(1) A minimum of two batches of premixture are prepared, the first with a lower ratio of ore to coke, and the second with a higher ratio of ore to coke.
(2) To maintain the central gas flow, the first batch is charged at the central area of the SF, and the second is charged at the circumference.
(3) The radial gas distribution is controlled by
  - changing the charging pattern of respective batches
  - changing the ratio of ore to coke in each batch.
(4) The appropriateness of the gas-flow distribution is determined from operational data, such as the coefficient of permeability, the top-gas temperature, the amount of dust generated, the thermal load in the furnace body, and the gas composition, and also from data measured by the shaft-gas sampler. A typical charging pattern is shown in Table III.

TABLE III
TYPICAL CHARGING PATTERN

Item	Batch 1	Batch 2
Coke, kg/batch	2 800	1 200
Ore, kg/batch	500	4 300
Number of rotations	9	9
Charging pattern*	$7^1 8^1 9^2 10^5$	$1^2 2^1 3^1 4^1 5^1 6^1 7^1 8^1$

*Large numbers show the position of the rotating chute during each rotation. Number 1 indicates the position nearest the furnace wall, while 10 indicates the furnace centre. Superscripts show the number of rotations at each position. Both batches are given nine rotations and, accordingly, the sum of the superscripts for each batch is nine.

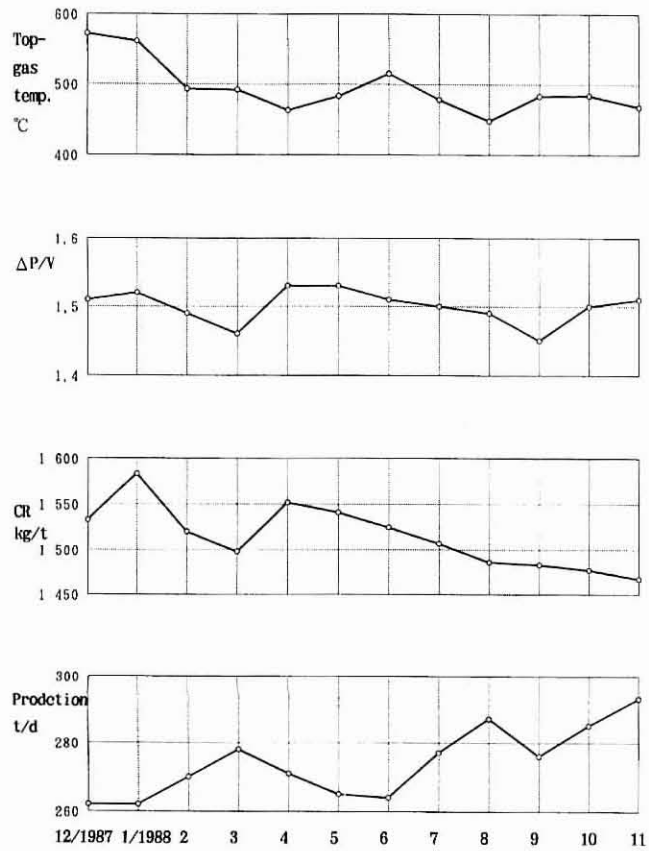

FIGURE 6. Trends in conditions for high-productivity operation

Optimum burden-distribution control for high-productivity operation

During the transition to higher production, priority was given to maintaining permeability in the shaft to meet the requirements of increased blast volume. Accordingly, charging patterns were selected so as to secure a good central gas flow. This made possible a smooth increase in the blast volume. However, in both December 1987 and January 1988, the central gas flow became excessive, resulting in increased top-gas temperatures and, consequently, a faster rate of generation. Thereafter, from February 1988 onwards, the charging patterns were adjusted so as to gradually depress the central gas flow while maintaining an adequate central flow with the aim of optimizing the burden distibution. The trends in top-gas temperature, pressure drop in the shaft, coke rate (CR), and output are shown in Figure 6. The pressure drop is shown as △P/V, △P being the pressure drop in the shaft in g/cm^2 and V the blast volume in Nm^3/min.

After July 1988, the top-gas temperature was stablized at less than 500 °C by optimization of the charging pattern. The reduction in the top-gas temperature made it possible to reduce the coke rate and thus secure a higher level of production. Stable high-productivity SF operation was realized after July 1988, and operation continued with no reductions in blast volume attributable to poor gas permeability until November of that year.

Production Increase by Oil Injection

Following the operational improvements discussed in the preceding sections, an average output of 285 t/d, which exceeded the design value of the SF, was attained in July 1988. In June 1989, oil injection was adopted to give a further increase in production.

Mechanism

The production of an SF can be increased by increases in blast volume or oxygen enrichment, or by a decrease in coke rate (fuel rate).

The blast volume of the Mizushima SF was already at the upper limit of the blower capacity, and the coke rate was at the lower limit, based on the thermal requirement of the furnace. From the viewpoint of equipment capacities, only oxygen enrichment was available as a means of increasing production, but further oxygen enrichment would have resulted in an increased TFT (as already discussed in connection with the first attempt to secure higher output) and was therefore not feasible. However, the decomposition of oil injected at the tuyères results in a decrease in the TFT, which permits a higher rate of oxygen enrichment in compensation for the lower TFT, thus making it possible to increase production. The TFT can be calculated from equation [2]. This formula can be used at the constant blast volume (570 Nm^3/min).

$$TFT = 62{,}5\, EO_2 - 7{,}5\, BM + 0{,}97\, BT - 11{,}6\, Oil + 1\,452, \quad [2]$$

where TFT is the theoretical flame temperature (°C),
EO_2 is the oxygen enrichment (%),
BM is the blast moisture (g/Nm^3),
BT is the blast temperature (°C), and
Oil is the oil injection rate (kg/min).

The possible production increase with oil injection was calculated at 9,7 t/d, based on oxygen enrichment without oil injection as 8,4 per cent, the oil/coke replacement ratio as 1,0, and the increase in oxygen enrichment as 1,0 per cent. The theoretical productivity is greatly affected by the oil/coke replacement ratio. In ironmaking blast furnaces, the replacement ratio is generally 1,0 to 1,6, but the replacement ratio was set at 1,0 with the SF since, in the SF, the indirect reduction ratio is low, and the hydrogen utilization, at 13 per cent, is lower than that in ironmaking furnaces.

Conditions

The quantity of oil injected is designed so that the additional oxygen enrichment (1,6 per cent, representing an increase from the 8,4 per cent base value to 10 per cent) will be sufficient for complete combustion of the oil injected when the blast volume is 570 Nm^3/min in normal SF operation. From calculations based on these conditions, the rate of oil injection was set at 750 l/h. The oxygen enrichment was then determined to be 10,9 per cent, which would maintain the TFT at its value prior to the oil injection. Since the optimum level of oil consumption for ironmaking blast furnaces is considered to be 40 to 60 kg/t of metal, this value was considered appropriate. Mizushima Ferro Alloy had already had experience with the 10,5 per cent value for oxygen enrichment, which was lower than the 12 per cent specified in the equipment design. These operating conditions were therefore considered practical.

Table IV shows the planned operating conditions with oil injection in comparison with the conditions used without oil injection.

TABLE IV
OPERATING CONDITIONS WITH AND WITHOUT OIL INJECTION

Item	Without oil injection	With oil injection
Production, t/d	285	309
Blast volume, Nm^3/min	570	570
Blast temperature, °C	810	810
Blast moisture, g/Nm^3	25	25
Oxygen enrichment, %	8,4	10,9
Oil injection, l/h	0	750
Coke rate, kg/t	1 490	1 436
Oil rate, kg/t	0	54
Slag rate, kg/t	552	542

Oil-injection Equipment

The design of the oil-injection equipment was based on that of ironmaking blast furnaces. The main specifications are shown in Table V.

TABLE V
SPECIFICATION FOR OIL-INJECTION EQUIPMENT

Item		Specification
Oil-injection quantity, kl/d		18
Oil-tank capacity, kl		60
Burner	Type	Plugged in tuyère
	Number	6
	Nozzle diameter, mm	3
Oil-tank heater, °C		40 to 50
Oil-pump capacity, kl/h		1,2
Oil heater, °C		80 to 120
Oil pressure, kg/cm^2		1,0 to 5,0

Unlike the burners used in the ironmaking blast furnace, which are set into the blowpipes, the SF burners are cast into the tuyères. This design was adopted because the diameter of the blowpipes is too small for the burner nozzles. Furthermore, melt-down problems could have occurred because the blowpipe is not cooled by water.

Oil is injected at 6 of the 13 SF tuyères, into alternate tuyères. In conventional blast-furnace practice, an oil-injection rate of 150 to 200 l/h per tuyère is considered necessary to prevent nozzle plugging and to maintain stable combustion. With the SF, however, the injection rate would be only 60 l/h per tuyère if oil injection were applied to all thirteen tuyères. Since this rate would be insufficient for stable combustion, the use of alternate tuyères was adopted.

The nozzle diameter is 3 mm, based on the results of experiments to determine the minimum practical nozzle diameter. Generally, nozzles of smaller diameter provide better combustion, but they are also more susceptible to plugging. Diameters of 3 mm and 5 mm were tested. Oil atomizing was found to be better with the 3 mm nozzle, and no plugging occurred. Before being injected, the oil is heated to between 80 and 120 °C to lower its viscosity.

Results of Oil Injection (June 1989 to March 1990)

Oil injection was started in June 1989. Figure 7 shows the

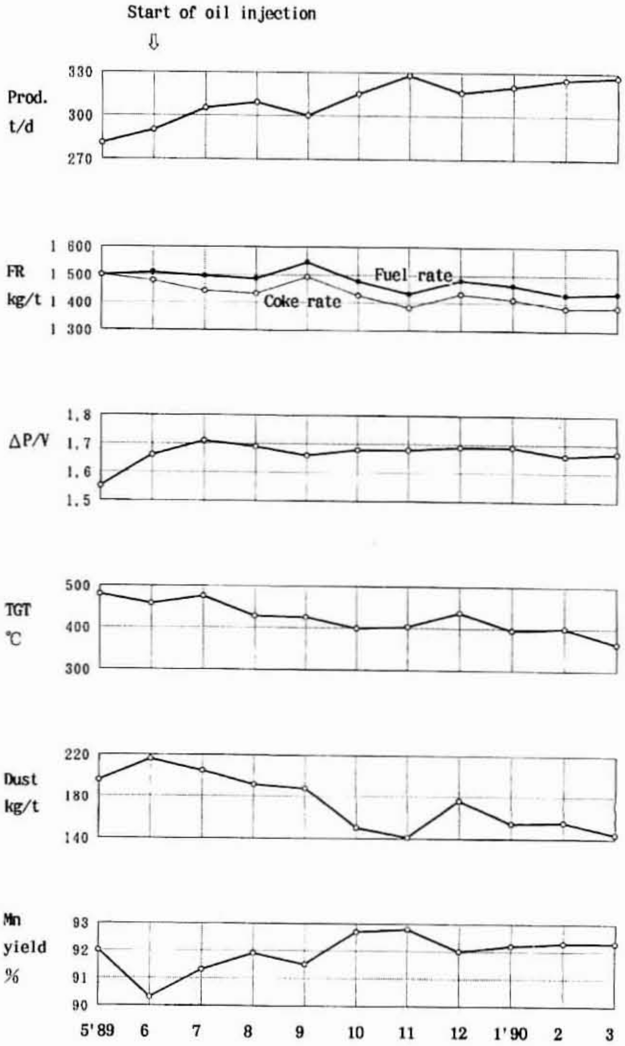

FIGURE 7. Oil-injection operation with the SF

trends in the operational parameters such as output, fuel consumption (FR), gas permeability (△ P/V), top-gas temperature (TGT), dust generation, and Mn yield between May 1989 and March 1990. The initially planned output of 309 t/d was achieved in two months. The fuel rate was then lowered from 1500 to 1430 kg/t of metal. The reduction in the fuel rate made possible a significant increase in production, to 328 t/d in November 1989.

During the same period, it was noted that the top-gas temperature gradually declined from 480 °C (before oil injection) to 400 °C. Although the reduction in the fuel ratio was related to the reduction in TGT, the latter was considered to be due mainly to the increased ore/coke ratio and higher oxygen enrichment, and was thus achieved by the optimization of burden-distribution control. Theoretically, increases in the oxygen enrichment result in corresponding decreases in nitrogen at the tuyère. This translates into a reduction in unit top-gas output, and in turn brings about an increase in the furnace of the heat-flow ratio (the ratio of the heat capacity of the solid burden to that of the gas), which in this case resulted in a lower TGT.

With the adoption of oil injection, the gas permeability deteriorated, rising from 1,55 to 1,7. This was caused by an increase in the volume of gas in the bosh of the furnace (which was generated in front of the tuyères) as a result of the oil injection and the shift to a higher ore/coke ratio, and gave rise to a higher rate of dust generation, since one of the initial aims of burden-distribution control was to maintain the central gas flow. Thereafter, however, adjustments to burden-distribution control practices made it possible to reduce the TGT and fuel rate, as discussed above. The generation of dust was reduced dramatically, and it stabilized at the considerably lower level of about 150 kg/t of metal after October 1989. At the same time, the Mn yield improved, and a consistent value of better than 92 per cent was achieved.

The source of dust in the SF includes fumes at the tuyères, degradation of the ore in the furnace shaft, and fines adhering to the charged ore. The reduction in dust generation experienced with oil injection is attributed mainly to the more effective capture, in the furnace shaft, of the fume dust generated at the tuyères. This improvement was made possible by the increased ore/coke ratio and decreased TGT.

According to measurements made with the vertical probe, Mn fume dust is present in relatively large quantities in areas with temperatures over 1000 °C and decreases in areas with temperatures under 1000 °C. This finding is explained by the condensation of Mn fumes on the surface of charged materials as the high-temperature fumes rise through the furnace and lose heat to the ore and coke in the furnace shaft.

The oil-injection equipment has functioned smoothly since its introduction in June 1989. Tuyère erosion, which had been feared, has been slight, and tuyère life is 1 year. The life of the nozzles is only about 4 months, but this is adequate to allow for their replacement during scheduled shutdowns of the shaft furnace.

Conclusion

At Mizushima Ferro Alloy Co. Ltd, an average monthly production of 285 t/d, or 0,72 t/m^3/d, was attained in August 1988 using a shaft-type ferromanganese smelting furnace with a rated output of 270 t/d. This achievement was made possible by the following techniques:

(1) burden-distribution control using a new bell-less top (Cardin type)

(2) control of the TFT

(3) control of the hot-metal temperature.

Oil injection was introduced in June 1989 in an effort to realize further increases in production. The aim of oil injection is to allow an increase in oxygen enrichment while controlling the TFT. (Since oil injected through the tuyères lowers the TFT, while oxygen enrichment increases it, a higher oxygen-enrichment ratio can be used when oil injection is adopted, permitting an increase in production.) According to plan, a 24 t/d increase was expected with an oil-injection rate of 750 l/h. In fact, an increase of 35 t/d has been achieved by use of a lower fuel rate (60 kg/t of metal) in conjuction with oil injection. The oil-injection equipment is operating smoothly, and production levels of over 320 t/d have now been realized.

In conclusion, the authors will continue to strive for technical breakthroughs in the area of high-productivity furnace operation.

Reference

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